The relative safety of Hawaii's drinking water

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The sources of drinking water

There are two types of drinking water sources: groundwater and surface water (the latter includes catchment of rain). Surface water runs over the surface of the earth in rivers and watercourses, or is stored in lakes and reservoirs. groundwater is water that is stored below ground level; it feeds artesian wells and springs. It is important to remember that untreated groundwater may not be the same thing as treated drinking water. A contaminant in groundwater represents a threat to a drinking water source but not necessarily a threat to health, if the contaminant's concentration is decreased before it becomes available as potable.

Each type of drinking water source has its own characteristic contamination problems. Surface water sources are more susceptible to contamination from animal or human fecal bacteria and viruses; animal waste, from cattle feedlots or poultry farms constitutes natural nitrate contamination. Artificial nitrate fertilizers are also washed down from fields by rain. In addition, humic acids from decaying plant material, when the water is chlorinated in order to disinfect against bacteria and viruses, combine with the chlorine to form chloroform and other possibly carcinogenic by-products [amazing! That chloroform is a product and that it is carcinogenic/Ed].

Underground water sources are usually shielded from contamination from bacteria, viruses, nitrates and plant acids; but are more susceptible than surface water to contamination by volatile, synthetic organic chemicals. Synthetic chemicals, being more volatile than water, pose little threat to surface-water drinking sources which are aerated, because aeration removes chemicals by natural evaporation into the atmosphere. Underground water is less aerated and not open to the atmosphere, so that contamination persists.

Both surface and groundwater in various locations across the nation have been found to be contaminated by nitrates, fluoride, arsenic, metals (barium, cadmium, chromium, lead, mercury, selenium and silver), and radionuclides. Fortunately, none of these contaminants is found in Hawaiian groundwater which is used for public drinking water, except for very low levels of nitrate, probably from fertilized fields, and fluoride in one or two wells.

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Here in Hawaii, groundwater currently supplies more than 90% of the total household water use, approaching 200-million gallons of water per day. Over 90% of the people who are drinking from public water supplies are drinking groundwater. According to the Hawaii Department of Land and Natural Resources, groundwater sources supply approximately 63% of the daily household use on Maui, 64% on Hawaii, 91% on Kauai, and at least 90% on Oahu, Lanai, Molokai, and Niihau. Very little comes from surface water sources such as streams, reservoirs and roof catchments, which means that drinking water contamination by bacteria, viruses, or disinfection by-products are and will be very rare. The predominant use of groundwater means that most of the threats to drinking water in this State are and will be volatile, synthetic organic chemicals.

Even though some groundwater sources are nearly 1000 feet below the surface, 14 different pesticides or industrial solvents have been confirmed as being present in Hawaii's groundwater in various locations. Positive identifications were confirmed by different tests, resampling and analyses, or by the validation of historic data. Listed are the 14 contaminants, together with the possible effects on health from an overdose (Table 1).

This is followed by maps of the locations of confirmed groundwater contamination by man-made chemicals, together with tables of the levels of contamination present as of June 1989. Contamination by natural sources, such as nitrates from animal farms, are not shown on the maps. The EPA guidance levels which are included in the tables for comparison are current as of May 1990 (Tables 3 through 7).

Origin of guidance levels and risk assessment

In the Middle Ages, Paracelsus (1493-1541) stated the axiom of toxicology: "All substances are poisons; there is none which is not a poison."[2]

All contaminants which might be ingested with drinking water are possibly toxic, given a sufficient dose. Therefore, the identification of a possibly hazardous chemical in groundwater is important, and so is its concentration. If a contaminant in Hawaiian groundwater is not carcinogenic, then proper treatment and removal can reduce its concentration below the threshold at which one could expect significant effects on health. If a contaminant is suspected to be carcinogenic, however, then it is generally assumed that there is no threshold in

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TABLE 1: POSSIBLE HEALTH EFFECTS AND SOURCES OF GROUNDWATER CONTAMINATION

Common Name	Possible Noncarcinogenic Effects from Ingestion by Humans or Animals[1]	EPA(CAG) Carcinogen Rating[2]	Potential Contamination Sources
Ametryn	Liver damage	Unclassified	Herbicide
Atrazine	Heart and liver damage; fetal/child development retarded	Possible	Herbicide
Carbon Tetrachloride	Liver, kidney, and lung damage	Probable	Solvent, dry cleaning agent
1,2,3 - Dibromochloro-propane (DBCP)	Male reproductive system, liver, and kidney damage	Probable	Pesticide (soil fumigant)
1,1-Dichloroethylene (DCE)	Central nervous system depression; a heart effect; liver and kidney damage	Possible	Solvent
1,2-Dichloropropane (DCP)	Gastrointestinal irritation, liver and kidney damage	Probable	Pesticide, solvent
Dieldrin	Liver, central nervous system, kidney and adrenal gland damage	Probable	Pesticide
Ethylene dibromide (EDB)	Male reproductive system, liver gastrointestinal, and adrenal gland damage	Probable	Gas addictive, soil fumigant, solvent
Hexazinone	No known effects	Unclassified	Herbicide
Lindane	Nerve damage and central nervous system seizures; liver and kidney damage; suppression of the immune system	Possible	Insecticide
Simazine	Liver, kidney, and brain damage	Possible	Herbicide
Tetrachloroethylene (PCE)	Central nervous system depression; liver and kidney damage	Probable	Solvent, dry cleaning agent
Trichloroethylene (TCE)	Central nervous system depression; a heart effect; liver and kidney damage	Probable	Solvent
1,2,3-Trichloropropane (TCP)	Decreased red blood cells; liver and kidney damage	Unclassified	Solvent, trace contaminant in certain pesticides

[1] Based on Health Advisories from the USEPA's Office of Drinking Water.
[2] Based on estimations from the USEPA's Health Hazard Assessment Group.

terms of effects on health. There will always be some theoretical probability of carcinogenesis, because there is no technique or treatment method that can remove 100% of a chemical contaminant.

Once the concentration of a contaminant in drinking water is determined, it can be compared with a standard. These guidelines can be obtained in print from the U.S. Environmental Protection Agency's Office of Drinking Water, or by a computer link from the Environmental Protection Agency (EPA)'s Integrated Risk Information System (IRIS). Every chemical listed on the IRIS is reviewed by the EPA monthly and revised as often as new data are obtained or risk-assessment procedures are refined. Here in the Hawaii Department of Health's Hazard Evaluation and Emergency Response (HEER) Office, updated information on the IRIS is reviewed almost every week.

In the U.S., the EPA, the National Institutes of Health (including the National Toxicology Program and the National Institute of Environmental Health Sciences), and the U.S. Public Health Service (including the Centers for Disease Control and the National Institute for Occupational Safety and Health) conduct research themselves, or finance the research projects at universities and certain private laboratories. The EPA's Office of Pesticides and Toxic Substances also reviews and contributes health-effects information from tests conducted by pesticide companies who want to register their pesticides for sale in the U.S.

At EPA, the Health Hazard Assessment Group (HHAG) collects data from research conducted both in the United States and abroad. After thorough review to select the one best toxicity study that has been done on each chemical contaminant, the HHAG then estimates reference doses (RfD) or carcinogenic potency factors (q_1*) which are used by the Office of Drinking Water to formulate its guidelines for noncarcino-

TABLE 2: DEFINITIONS OF APPLICABLE DRINKING WATER STANDARDS

"MCL" means a maximum contaminant level or the maximum permissible level of a contaminant in water which is delivered to any user of a public water system. MCLs are the only federally enforceable drinking water standard. A "pMCL" means that EPA has proposed a MCL for that contaminant.

A "Lifetime Health Advisory" (LHA) describes a non-regulatory concentration of a drinking water contaminant at which adverse health effects would not be anticipated to occur over a lifetime exposure of 70 years duration. The advisories are based on data describing non-carcinogenic risk from such exposure.

"10(-6)" indicates those chemicals which EPA considers to be potential human carcinogens, EPA estimates a "cancer risk level" as the level at which an individual who consumes water over his or her lifetime (70 years) would have no more than a one-in-a-million chance of developing cancer as a direct result of drinking water containing the contaminant.

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genic and carcinogenic contaminants, respectively.

In the case of a noncarcinogenic substance, classic toxicology methods can be applied; risk estimates have relatively firm foundations. A reference dose (RfD) is expressed in mg/kg/day, or milligrams of toxic substance absorbed per kilogram of body weight per day. RfD is a new acronym for the old ADI, Acceptable Daily Intake. The following is an example of the calculation of a Lifetime Health Advisory (LHA) guidance level, using atrazine, a contaminant listed in Table 1.

Five studies were considered in the development of the LHA, 3 using rats and 2 using dogs. In these studies, dogs exhibited toxic responses at lower doses than rats, and therefore the guidance levels derived from the dog studies were expected to be more protective of public health. A 2-year dog-feeding study (Woodard, 1964) was initially used for the calculation of the RfD and LHA, but since there was a lack of information on the purity of the test material and the hematological data were incomplete, a 1-year dog-study (Ciba-Geigy, 1987) was considered to be better because the researchers used 97%-pure, technical atrazine. The No Observed Adverse-Effect Level (NOAEL) in this study at 0.48 mg/kg/day, which was based on the absence of cardiac pathology or any other adverse clinical, hematologic, biochemical or histopathologic effect in dogs, and was supported by the other 4 studies. This animal NOAEL of 0.48 mg/kg/day was divided by the standard National Academy of Sciences (NAS) / EPA uncertainty factor of 100 for a well-conducted animal study, to give a human RfD of 0.0048 mg/kg/day. The uncertainty factors are 10, to adjust for intra-species variation in sensitivity, multiplied by 10, to adjust for potential inter-species variation in sensitivity, possibly multiplied by other factors of 10 (if a study was not well-conducted and if there was reason to doubt the findings, or if there was a potential for synergism).

A risk assessment based on a well-conducted human study might have an uncertainty factor of only 10, whereas an emergency-situation risk assessment based on an unsupported, suspect animal study might have an uncertainty factor of 1000 or larger.

Once the human RfD is obtained, the calculation proceeds in a conventional manner:

$$\frac{(0.0048 \text{ mg/kg/day})\ (70 \text{ kg})\ (0.20)}{(2 \text{ liters/day})\ (10)} = 0.003 \text{ mg/liter} = \text{LHA}$$

where

0.0048 mg/kg/day = RfD
70 kg = assumed average body weight of an adult;
0.20 = assumed 20% of total intake from drinking water (assumed 80% of total intake from residues in food);
2 liters/day = assumed daily adult water consumption; and
10 = additional uncertainty factor, to account for possible carcinogenicity of atrazine which was indicated in 1 of the 3 rat studies (Ciba-Geigy, 1986).

Similar findings of mammary tumors in female rats dosed with 3 pesticide analogs of atrazine (simazine, propazine, and terbutryn) support the possible carcinogenicity of atrazine.

Therefore, the Lifetime Health Advisory was determined to be 0.003 mg/L, or 3 micrograms per liter, which is the guidance level stated in the Tables above.[4]

Estimating the risk from exposure to confirmed or suspected carcinogenic substances is not as conventionally simple as estimating an LHA. In the National Academy of Sciences' 1977 *Drinking Water and Health, volume 1,* 4 basic assumptions for assessing the irreversible human effects of long and continued low-dose exposure to carcinogenic substances are stated:

Principle 1: Effects in animals, properly qualified, are applicable to man.

Principle 2: Methods do not now exist that establish a threshold for long-term effects of toxic agents.

Principle 3: The exposure of experimental animals to toxic agents in high doses is a necessary and valid method of discovering possible carcinogenic hazards in man.

Principle 4: Materials should be assessed in terms of human risk, rather than as "safe" or "unsafe"[3].

Since cancer is a disease with several different causes and processes, many of which are unknown, the prediction of possible cancer risk from low environmental doses, extrapolated from very high experimental doses, requires the use of imperfect models. There are at least 19 different cancer models, none of which can be experimentally verified. These models are divided into 3 categories (a) mechanistic (eg, 1-hit, multihit, multistage); (b) tolerance distribution (eg, probit, logit, Weibull); and (c) time-to-occurrence (eg, lognormal, Weibull). The mechanistic models assume that all individuals are equally susceptible to cancer, which we know is not true, such that cancer risk-estimation becomes a simple mathemati-

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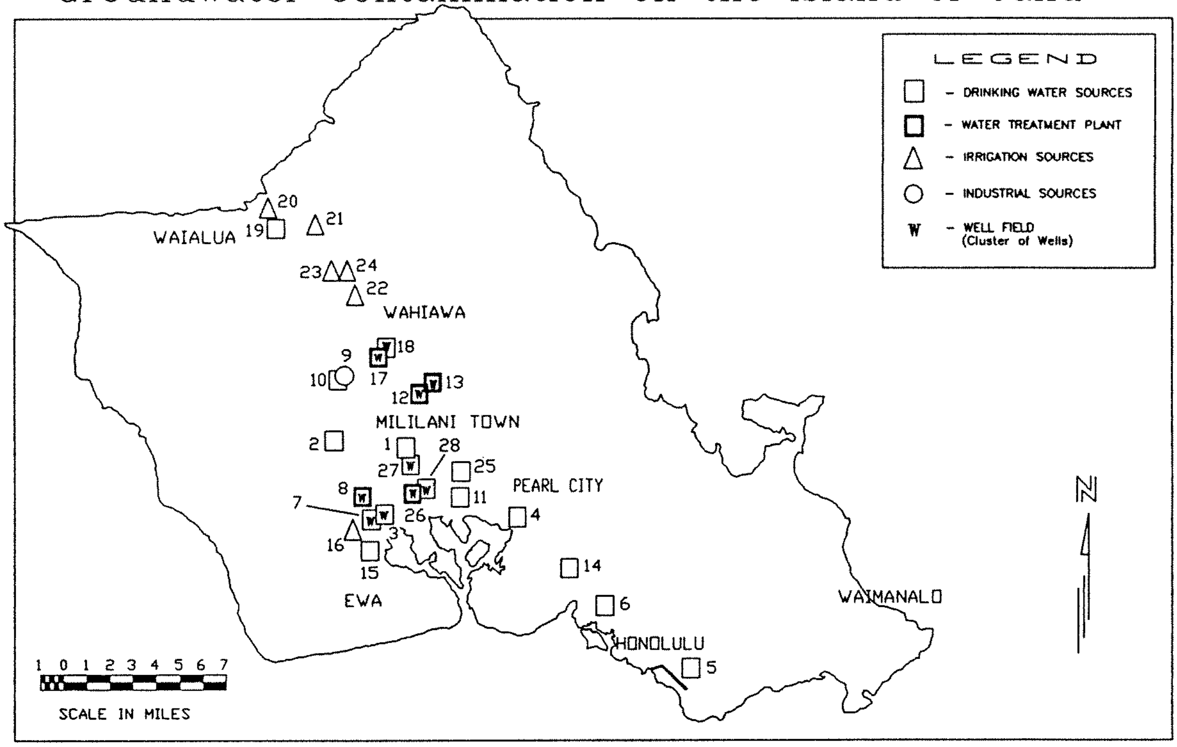
Groundwater Contamination on the Island of Oahu



This Map Contains the Last Confirmed Results From Contaminated Groundwater Wells

NO.	CONTAMINANT		DETECTED LEVEL (in ppb)	APPLICABLE DRINKING WATER STANDARDS (in ppb)	
1	TCE		0.70	5.0	MCL
2	DBCP		0.01	0.0007	10^{-6}
	PCE		0.22	5.0	pMCL
3	Atrazine		0.114	3.0	LHA
	TCP		0.20	0.06	LHA
4	PCE		0.03	5.0	pMCL
5	PCE		0.03	5.0	pMCL
6	Dieldrin		0.008	0.002	10^{-6}
7	Atrazine		0.083	3.0	LHA
	TCP		0.65	0.06	LHA
8	DBCP	influent	0.02	0.0007	10^{-6}
		effluent	<0.02		
	TCP	influent	0.65	0.06	LHA
		effluent	<0.20		
9	PCE		1.65	5.0	pMCL
	TCE		3.70	5.0	MCL
10	Carbon Tetrachloride		0.69	5.0	MCL
	DCE		0.20	0.06	10^{-6}
	TCE		0.83	5.0	MCL
	PCE		2.60	5.0	pMCL
11	PCE		0.3	5.0	pMCL
12	DBCP	influent	0.07		
		effluent	<0.02	0.0007	10^{-6}
	DCP	influent	0.64		
		effluent	---	0.6	10^{-6}
	TCP	influent	1.50		
		effluent	<0.20	0.06	LHA
13	DBCP	influent	0.07		
		effluent	<0.02	0.0007	10^{-6}
	DCP	influent	0.74		
		effluent	---	0.6	10^{-6}
	TCP	influent	1.50		
		effluent	<0.20	0.06	LHA
14	Dieldrin		0.009	0.002	10^{-6}
15	Atrazine		0.035	3.0	LHA
16	Atrazine		0.100	3.0	LHA
17	TCE	influent	8.50		
		effluent	<1.00	5.0	MCL
	PCE	influent	0.37		
		effluent	<1.00	5.0	pMCL
18	Carbon Tetrachloride		0.58	5.0	MCL
	PCE		0.38	5.0	pMCL
19	TCP		0.21	0.06	LHA
20	Lindane		0.001	0.03	10^{-6}
21	DBCP		0.01	0.0007	10^{-6}
	TCP		0.29	0.06	LHA
22	DBCP		0.02	0.0007	10^{-6}
	TCP		0.37	0.06	LHA
23	DBCP		0.115	0.0007	10^{-6}
24	DBCP		0.01	0.0007	10^{-6}
	TCP		0.43	0.06	LHA
25	DBCP		0.024	0.0007	10^{-6}
	TCP		0.21	0.06	LHA
26	EDB	influent	0.055		
		effluent	<0.02	0.0004	10^{-6}
	TCP	influent	<0.20		
		effluent	<0.20	0.06	LHA
27	TCE		0.55	5.0	MCL
	TCP		0.25	0.06	LHA
28	TCP		0.20	0.06	LHA

NOTE: Due to the number of wells in close proximity to each other, some sites are represented by wellfields and may contain several wells.
Possible natural contaminants such as nitrates have not been included.

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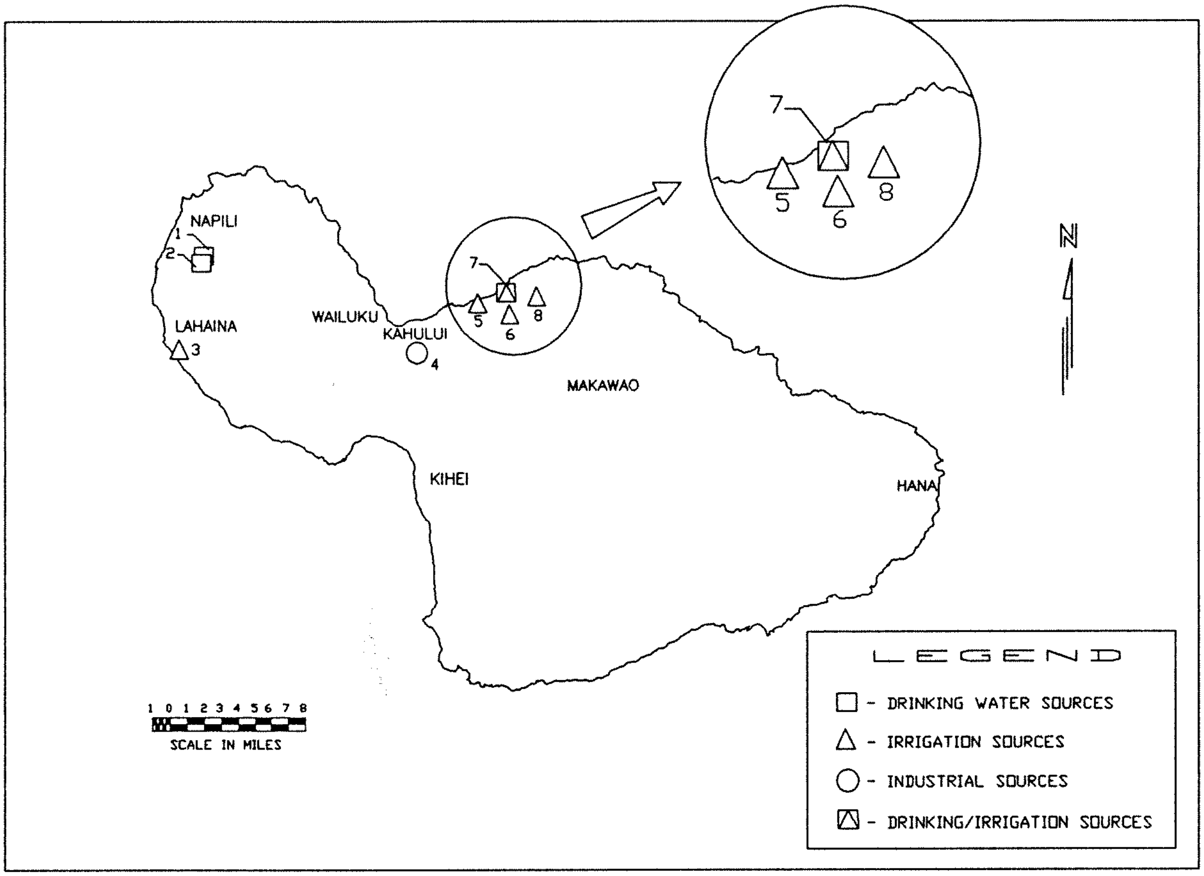
Groundwater Contamination on the Island of Maui



This Map Contains the Last Confirmed Results From Contaminated Groundwater Wells

NO.	CONTAMINANT	DETECTED LEVEL (in ppb)	APPLICABLE DRINKING WATER STANDARDS (in ppb)	
1	Trichloropropane	0.200	0.06	LHA
2	Trichloropropane	0.300	0.06	LHA
3	Atrazine	0.110	3.0	LHA
4	Atrazine	1.000	3.0	LHA
	Ethylene Dibromide	0.040	0.0004	10^{-6}
5	Atrazine	0.600	3.0	LHA
6	Ethylene Dibromide	0.028	0.0004	10^{-6}
7	Trichloropropane	0.430	0.06	LHA
8	DBCP	0.091	0.0007	10^{-6}
	Ethylene Dibromide	0.067	0.0004	10^{-6}
	Trichloropropane	0.430	0.06	LHA

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NOTE: Possible natural contaminants such as nitrates have not been included

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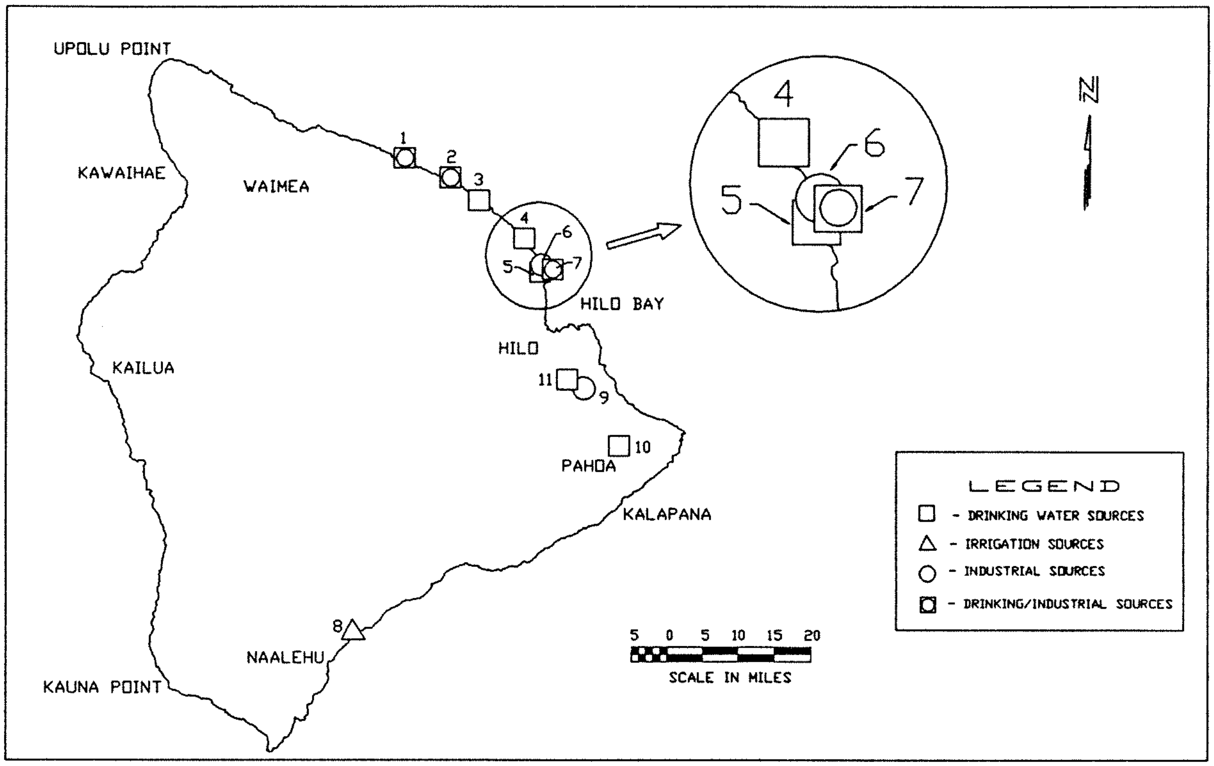
Groundwater Contamination on the Island of Hawaii



This Map Contains the Last Confirmed Results From Contaminated Groundwater Wells

NO.	CONTAMINANT	DETECTED LEVEL (in ppb)	APPLICABLE DRINKING WATER STANDARDS (in ppb)	
1	Atrazine	0.270	3.0	LHA
	Hexazinone	0.110	200.0	LHA
2	Atrazine	0.270	3.0	LHA
3	Atrazine	0.400	3.0	LHA
	PCE	0.130	5.0	pMCL
5	Atrazine	0.300	3.0	LHA
	Hexazinone	0.060	200.0	LHA
6	Atrazine	0.400	3.0	LHA
	Hexazinone	0.090	200.0	LHA
7	Atrazine	1.300	3.0	LHA
	Hexazinone	0.090	200.0	LHA
8	Atrazine	0.140	3.0	LHA
9	Atrazine	0.260	3.0	LHA
	Ametryn	0.880	60.0	LHA
10	Atrazine	0.300	3.0	LHA
11	Atrazine	0.100	3.0	LHA

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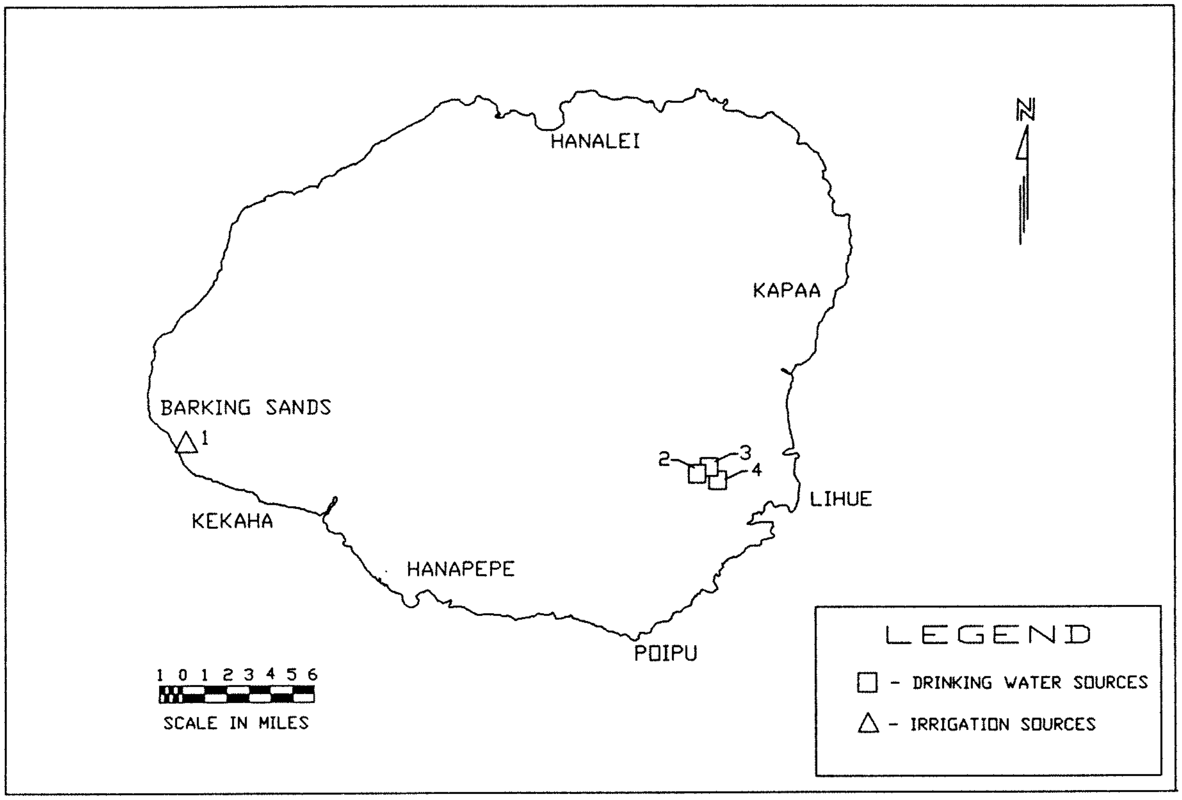
NOTE: Possible natural contaminants such as nitrates have not been included.

Groundwater Contamination on the Island of Kauai



This Map Contains the Last Confirmed Results From Contaminated Groundwater Wells				
NO.	CONTAMINANT	DETECTED LEVEL (in ppb)	APPLICABLE DRINKING WATER STANDARDS (in ppb)	
1	Atrazine	2.500	3.0	LHA
	Ametryn	0.800	60.0	LHA
	Simazine	0.200	1.4	LHA
2	Atrazine	0.060	3.0	LHA
3	Atrazine	0.200	3.0	LHA
4	Atrazine	0.100	3.0	LHA

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NOTE: Possible natural contaminants such as nitrates have not been included

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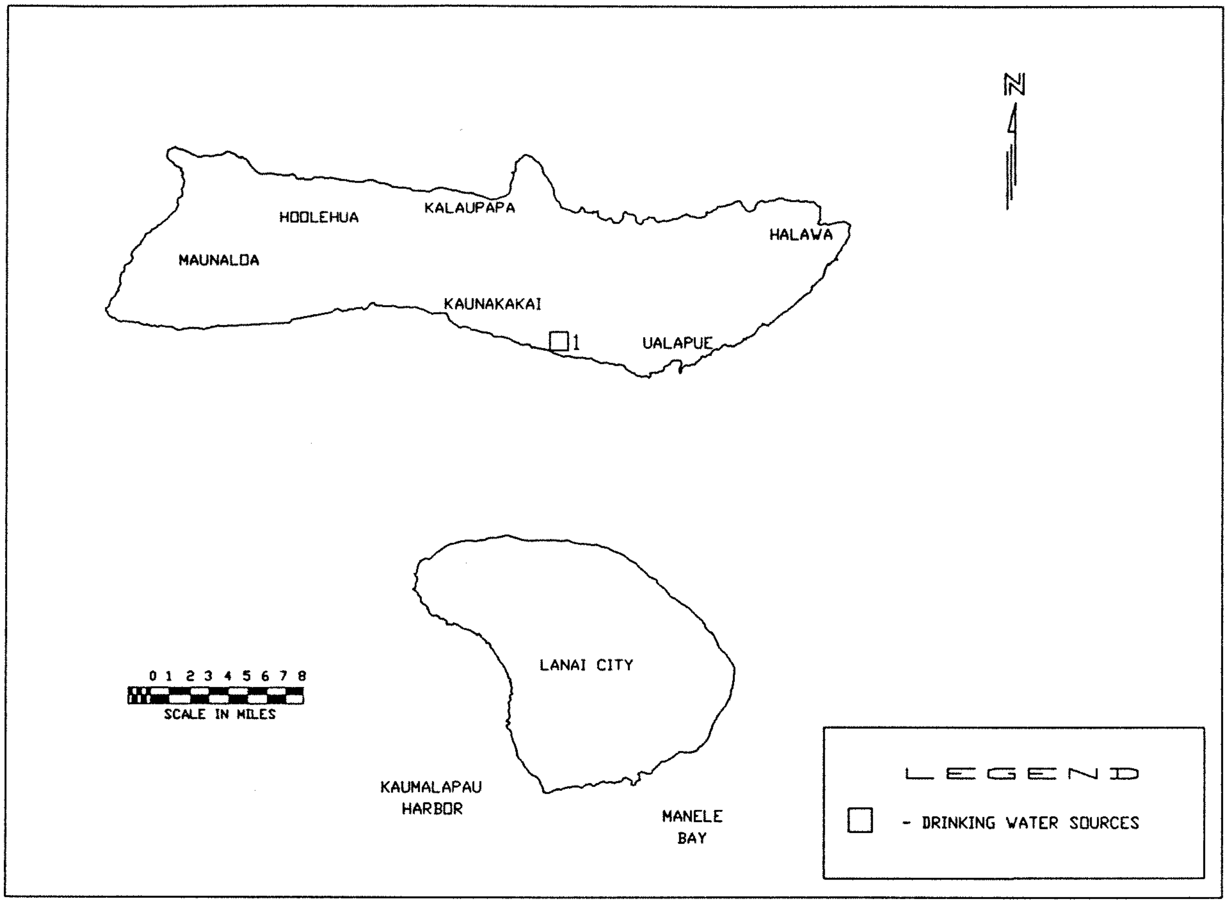
Groundwater Contamination on Molokai and Lanai



This Map Contains the Last Confirmed Results From Contaminated Groundwater Wells			
NO.	CONTAMINANT	DETECTED LEVEL (in ppb)	APPLICABLE DRINKING WATER STANDARDS (in ppb)
NO CONFIRMED CONTAMINANTS DETECTED			

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NOTE: Possible natural contaminants such as nitrates have not been included

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cal exercise. The tolerance distribution models attempt to allow for individual sensitivity to carcinogens, but the mathematics are difficult. The time-to-occurrence models are useful when attempting to predict the cancer risk from a chemical which causes cancer after only a relatively short duration of exposure[1,5].

The one-hit model generates the lowest, most conservative, most health-protective guidance level, but the one-hit model appears to be an appropriate risk predictor only for cancers caused by radiation. The EPA and NAS believe that the most appropriate risk predictor for cancers caused by most chemicals is the modified multistage model, which is not the most conservative model. The modified multistage model was used to estimate all of the EPA guidance levels of 10^{-6} in the Tables, except for that of ethylene dibromides (EDB). EDB was used as a fumigant in grain silos and was a soil fumigant for nematodes in pineapple fields, and its risk was estimated using a combination of the modified multistage and Weibull models because EDBs caused cancer in animals after an exposure duration of less than a lifetime. Cancer-risk estimation models extrapolate a straight line from high-dose carcinogenesis data in a straight line and the slope of the line is the cancer potency factor, q_1*, or "q-star." The q-star multiplied by the absorbed daily dose of a carcinogen gives the cancer risk of a 70-year lifetime's exposure.

There are at least 7 conservative assumptions built into EPA's estimates of carcinogenic risk. For example, the assumptions regarding a daily intake of 2 liters of water and 100% intestinal absorption of an ingested contaminant will overestimate the cancer risk by 2 to 100+. The extrapolation of animal data to humans on the basis of surface area, rather than body weight, will overestimate the cancer risk by 5 to 13[5].

Prevention of future contamination

There are many federal, State and county programs that are presently involved with the protection of groundwater quality in Hawaii. For example, the U.S. EPA administers a sole-source aquifer program; the State Department of Land and Natural Resources and the Honolulu Board of Water Supply administer a watershed management program; the State Department of Agriculture regulates the large-scale use of pesticides and is working with the University of Hawaii to develop ways to estimate how rapidly chemicals leach through soils in different locations on every island. The State Department of Health administers an underground injection control program, formulates the overall groundwater quality protection strategy and, of course, attempts to minimize the health risk of contaminants in drinking water.

In an agricultural state such as California, great quantities of pesticides have been deliberately applied to, or accidentally spilled on the ground over the years. Once pesticides have leached below the 3-foot-deep "vadose zone", where microbes which can degrade chemicals live, there is no further degradation unless a pesticide is susceptible to hydrolysis. One University of California (Riverside) groundwater expert has estimated that rainwater is leaching pesticides downward through California's sandy soils at a rate of 6 to 12 inches per year. Unless a layer of impermeable clay arrests the leaching, this could threaten water supplies, which are only 20 feet below the surface in some places, in about 20 years. A similar potential for future contamination exists here in Hawaii. Hawaii's greater rainfall increases the threat, but Hawaii's clay soils and deeper drinking-water aquifers decrease the threat. However, the drilling of wells through clay layers provides a conduit for swift leaching of pesticides into groundwater, which is probably what occurred in Kunia on Oahu. This means that pesticides applied many years before protective programs existed move slowly downward, so that prevention of future contamination of Hawaii's groundwater sources may already be too late. On the reassuring side, however, surveillance and protection of the treated drinking water which is served to people will continue to improve.

Conclusion

This paper has attempted to catalogue the contamination of Hawaii's groundwater source by man-made organic chemicals, comparing them to EPA guidance levels and explaining the origin of those standards. In the opinion of this writer, having compared the 1989 levels of contamination to the guidance levels, and having had EPA experience with the greater varieties of drinking water contamination found in other states, Hawaii has relatively the safest drinking water in the nation. Also, given that the EPA and the states oversee drinking water quality in the U.S. better than the way the appropriate agencies in other countries do it, Hawaii may have one of the safest drinking water supplies in the world.

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